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Advanced Communications Satellites

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ABSTRACT

With the increase in demand for satellite communications services has come the advent of shortages in available transponder capacity, especially at C-band. Demand for satellite distributed video services has resulted in over subscription to the FCC for the remaining orbital slots at that frequency. Interest has shifted to the Ku-band frequency and currently carriers are rapidly moving to secure orbital slots for future satellite development. Projections of communications service demands over the next decade indicate growth in voice, data and video services such that saturation of both C-band and Ku-band will occur by 1990. Emphasis must and will shift to Ka-band (20/30 GHz) frequency for fixed-satellite service. This gives rise to an opportunity to apply advanced technologies such as multibeam antennas coupled with on-board satellite switching to allow implementation in this band of very high capacity satellite systems to meet the demand.

This paper will present satellite system concepts that are likely in the 1990's and are likely to bring a new dimension to satellite delivered communication service. The NASA 30/20 GHz communications satellite system demonstration program will be discussed with emphasis on the related technology development.

INTRODUCTION

As we move from the decade of the seventies to the eighties, the use of communication satellite systems will continue to increase. In 1978 the prospects for profitable operation of domestic satellite systems was marginal at best. The growth of the cable TV systems using satellite distribution changed the market situation dramatically for satellite transponders with the buyers market changing almost overnight to a sellers market. This has created an over subscribed condition in the FCC for C-band (6/4 GHz) orbital positions. Attention is being focused on the available Ku-band positions as the next best alternative to C-band slots. Three carriers have current filings for use of Ku-band (14/12 GHz) orbital positions with other filings pending. Although C-band transponders have proven to be profitable, particularly for TV distribution, it remains to be proven that Ku-band transponders will be money makers. If, of course, communication satellite systems are to expand their service offerings, not only must cost competitive systems be developed at Ku-band, but they must also extend to the use of Ka-band (30/20 GHz). Satellite Business Systems (SBS) will begin operation with their Ku-band system in January 1981 following launch of their first satellite in October 1980. The focus of the SBS system will be on fixed-satellite service for major business firms. The SBS system in principle may be the forerunner of the higher frequency satellite systems of the eighties.

As we look ahead to continued growth in satellite communications, it will be necessary to develop needed technology to enable the growth and capacity and the effective utilization of the geostationary orbit frequency spectrum. Technology must not only permit expansion of the capacity of the currently used bands at 6/4 GHz and 14/12 GHz but must also direct

attention to the next higher frequency band, 30/20 GHz, allocated for fixed-satellite service.

This paper will discuss the current NASA sponsored program in systems and technology development associated with the Ka-band frequencies. Two general types of services will be presented; Trunking Services and Customer Premises Services. The technology developed at Ka-band should and will be applied at the lower frequency bands as appropriate.

BACKGROUND

In June of 1979 NASA chaired a session at the International Conference on Communications, ICC, here in Boston. At that time NASA presented its plans for increasing its involvement in communications satellite R&D efforts in an attempt to stimulate technology development in areas related to increased orbit capacity and frequency spectrum effective utilization. The focus of the NASA program in the near term was technology related to Ka-band since the carrier industry already had plans for using Ku-band for commercial service. The plan presented at that time indicated a parallel activity which included a continuation of systems studies focused on applications of the band for commercial service as well as an aggressive technology development of the critical elements of a Ka-band satellite/ground system.

The expansion of the use of C-band in the last year and a half has dramatized the need for extending commercial services to Ku-band and Ka-band in the near future. Both Ku-band and Ka-band, however, experience rain attenuation effects on signal quality not present at C-band. This increased attenuation, particularly at Ka-band, requires special attention if competitive service offerings are to be made. To illustrate the effect of rain on signal outage, the hours of expected outage at four locations in the U. S. is shown in figure 1 as a function of the link margin provided. Even with 10 dB of link margin up to 17 hours of outage might be expected in Washington, D. C. for the uplink at 30 GHz compared to one hour at 12 GHz. Outage at C-band would be negligible. Compensation in the system configurations must be made if competitive service offerings at Ka-band, and perhaps even Ku-band, are to be made.

As we move up in frequency, the use of increased spacecraft antenna gain to help compensate for the expected rain fades appears to be appropriate. For example, at a 99.5% link availability comparable spacecraft transponder powers will occur at Ka-band and Ku-band when a 0.8 degree spot beam is used at Ka-band compared to a conus beam at Ku-band. The use of spot beams will increase the complexity of satellite systems, however they will, using frequency reuse techniques, permit higher capacity satellites at modest increases in satellite size.

PROGRAM CONTENT

To present an overall perspective of the structure of the 30/20 GHz program, the first chart (figure 2) shows the program divided into four phases. The first phase which was conducted in 1978 and 1979 was primarily composed of system and market studies addressing the operational

application of the 30/20 GHz band. The results of Phase I were presented at ICC 1979 here in Boston. There were two main system studies conducted; one each by Ford Aerospace and Hughes Aircraft with supporting studies by TRW, General Electric and Mitre Corporation. In parallel, two major market studies were conducted by Western Union and U.S. Telephone and Telegraph. The results of the two types of studies were combined to define potential operational system configurations which could respond to the expected market for two classes of services; Trunking Service and Customer Premises Service.

The promising results of Phase I prompted NASA to proceed to Phase II of the program. Two major thrusts are included in this phase. One is directed toward defining the overall requirements of a flight demonstration satellite/ground system capable of verifying the state of readiness of the critical technology necessary to make a 30/20 GHz system commercially viable. The second thrust and perhaps the more important is the critical element technology development as identified by the results of Phase I. The third phase of the program deals with the development and flight test of the technology demonstration system and the conduct of the experiment program involving both technical and service-type experimentation. In addition to the primary system development activity, follow-on technology development is planned to extend the state of the technology beyond that committed to flight in the demonstration system.

The fourth and perhaps the most important phase is the deployment of operational systems using the 30/20 GHz band. If the first three phases of the program are successful, operational implementation by the communications carriers would follow closely behind the activity of Phase III.

In the balance of the paper, a detailed discussion of Phase II, which is currently in progress, will be presented.

PHASE II COORDINATION

Phase II is a result of a complex combination of many inputs by interested and involved groups and individuals. An illustration of the extent of this interaction is given in figure 3.

Starting with the desired output of this phase, the demonstration system definition phase will include the overall project plan for system development, a definition of the system requirements as well as identification of the specific technical requirements, an assessment of the readiness of the critical technology elements, and the overall experiment program plan defining both the technical and service demonstration experiments. A very important element of this phase is the identification of the system acquisition plan which may include direct industry involvement from a sharing standpoint at the outset of system development.

The major player in this overall process, and perhaps in all phases of the program, is the NASA Ad Hoc Advisory Committee currently chaired by Jack Harrington of Comsat. The committee includes notable representatives of both the system supplier and service supplier industries. Their

contribution provides timely and sage review and critique of both planning and progress of the program as well as providing NASA with an insight to the industry philosophy relative to roles and responsibilities of both Government and industry in the conduct of the program.

A Carrier Working Group made up of representatives of all the major satellite carriers, new and old, provide NASA, on a continuing basis, with definition of functional requirements to be met by future satellite systems. These requirements are manifested in an experiments requirements document created by the working group and represents the experiments necessary to demonstrate the readiness of not only the technology but its application as well. Detailed reviews of the results of both the system studies and the technology development are conducted.

Inasmuch as the military-allocated band is adjacent to the commercial band at 30/20 GHz, a close coordination between NASA and DOD is part of the program activity. Several of the critical technology elements under development are co-funded between DOD and NASA. Continued and expanded cooperation is expected as the program continues to develop.

A broad cross section of the industry is already under contract to NASA to develop technology elements considered critical to program success. The purpose of the activities is to develop the hardware necessary to demonstrate the technical feasibility of technology through proof-of-concept model testing. In all cases multi-year developments are planned.

Finally, the major system contractors are involved in developing system designs to permit affordable demonstration program alternatives. Currently, both Hughes Aircraft and TRW are under contract in parallel to define system options, create development plans including schedules and costs, and establish experiment plans based on the experiments requirements document developed by the Carrier Working Group.

By coordinating the inputs of all the interested and involved players, NASA expects to successfully complete Phase II in 1981.

In the remainder of the paper, the status of the technology development and the system study activities will be presented.

PHASE II TECHNOLOGY DEVELOPMENT

The objective of the technology ready program (see figure 4) is to provide through feasibility demonstrations of proof-of-concept hardware the technology required to enable a cost-effective and spectrum-conservative implementation of Ka-band thereby decreasing potential development risk for future flight systems. The schedule calls for completion of the technology ready program by the end of 1982. As a general philosophy wherever possible parallel contracts for all the key subsystems are planned. This permits a multi-path approach to technology solutions as well as developing multiple sources for hardware in the future.

The technology elements either under development now or planned for

development in the near future are illustrated in figure 5. Seven of the eight critical elements are currently under contract. The one area not yet under contract is the low-cost ground terminals. RFP's for related technology in this area will be released later this calendar year.

Since the state of the current technology in each of the areas is different, the maturity of the technology will be different at the end of the technology ready program. An illustration of the assessed status is shown in figure 6. The Proof-of-Concept (POC) configuration will be a complete subsystem development using, wherever possible, flight-type materials. Both functional as well as thermal vacuum testing is planned except for the antenna system where thermal vacuum is not planned. The POC models will vary somewhere between breadboard and prototype development. The antenna and baseband processor are nearer to breadboard with the transmitter, receivers and switch matrix nearer to prototype.

A summary of the current technology contracts is given in figure 7. The subsystem or element is shown along with the companies conducting the development and an estimate of the contract value.

The flow diagram of the technology contracts is shown in figure 8. Design concepts using 1982 and 1987 forecasts of technology are conducted followed by Proof-of-Concept (POC) model design based on 1982 technology model fabrication and testing and analysis of testing results. An assessment of the expected reliability is conducted following model testing.

PHASE II ALTERNATE SYSTEM CONCEPTS

The alternate system design concepts for the demonstration system are being studied by Hughes Aircraft and TRW in parallel contract efforts. The design concepts are in response to the functional requirements being developed in the Carrier Working Group. A baseline set of requirements was defined at the start of the studies. Both contractors developed system configurations to meet the baseline requirements and determined both development schedules and costs for their baseline configuration. Following efforts on the baseline concept, each contractor is expected to develop two other concepts having greater or less capability than the baseline in order to develop a data base of information for NASA to define the demonstration system and acquire it through competitive procurement. A pictorial representation of the Phase II study results are shown in figure 9. The output of the studies will provide information dealing with cost vs experiment value with a maximum affordable cost limit and a minimum experiment value limit to be determined. The concepts studied will allow a selection of system capability as a function of return in terms of experiment value for the demonstration system.

Baseline Concepts - To provide a perspective of a 30/20 GHz system, the baseline configuration resulting from the functional requirements will be discussed in some detail. The baseline program assumed a two flight mission program. The requirements of Mission A are shown in figure 10. The target launch date was 1986 with the system configuration to provide Trunking and Limited Customer Premises Services via seven fixed high gain

spot beams; nominal spot size was 0.3 degrees. Emergency service was to be provided via a 1.5° steerable spot beam. The terrestrial system included a Master Control Station, trunking terminals using site diversity terminals, small Customer Premise terminals and transportable emergency terminals.

Mission B, shown in figure 11, added a high gain scanning beam system to the spacecraft to allow wide-area coverage for Customer Premises Service. Interconnect was required between fixed spot beams and the scanning beam(s).

A summary description of the resulting spacecraft is shown in figure 12. Both Hughes and TRW developed concepts covered by the summary, however, the spacecraft configurations were quite different. An artist's rendition of the TRW configuration is shown in figure 13. It is a three-axis stabilized spacecraft with a dry weight of 2,300 lbs. Two 14 foot parabolic offset fed reflectors are used to provide conus coverage. One antenna provides eastern coverage and the other western coverage. The spacecraft design features are listed in figure 14.

The Hughes configuration uses a spin stabilized spacecraft system shown in an artist's sketch in figure 15. It utilized a single 14 foot offset fed parabolic reflector. Spacecraft dry weight is 2,750 pounds. The spacecraft design features are listed in figure 16.

Typical ground terminal systems are shown in the following figures.

The trunking terminals in the baseline (see figure 17) used 12 meter antennas and site diversity. Two 12 meter antennas connected with a fiber optic link were placed 10 kilometers apart to mitigate against the expected rain fade.

The Customer Premises Services terminals are shown in an artist's sketch in figure 18. Antennas ranging from 3 to 5 meters would be used at a customer's site, thus eliminating the need for terrestrial tails.

A typical emergency terminal setup is shown in figure 19. Antenna diameters less than 2 meters would be used.

Following the baseline concept development, both contractors are required to study spacecraft systems smaller than that of the baseline down to a SUS-D class spacecraft. Single mission programs vs two mission programs will be evaluated. Development plans, schedules and development costs will be determined. From the resulting data base a final set of functional requirements will be developed. A RFP will be issued next summer to the industry to finalize the alternate design concepts and develop proposals for the flight demonstration system development. A single award for system development is anticipated as a result of the alternate concept activity. A flight system development could start as early as June of 1983.

CONCLUDING REMARKS

NASA has in the past year increased its activities in communications satellite systems research and development. The major focus of the program is the technology development and demonstration of critical technology elements of the 30/20 GHz frequency band. The effort involves intensive interaction between industry and Government in all phases of the program. A major program milestone will be a new start authorization in FY 1983 for a demonstration satellite system scheduled for launch in 1987.

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HOURS PER YEAR OF EXPECTED OUTAGE ON A SATELLITE LINK DUE TO RAIN*

LOCATION	FREQUENCY	3 dB MARGIN	10 dB MARGIN
AUSTIN, TEXAS	12 GHz	9 h	2 h
	20	23	6
	30	51	12
BLACKSBURG, VIRGINIA	12	18	1
	20	88	4
	30	175	8
HOLMDEL, NEW JERSEY	12	17	2
	20	40	5
	30	83	7
WASHINGTON, D.C.	12	5	1
	20	53	9
	30	105	17

*FROM SATELLITE BEACON MEASUREMENTS, ELEVATION ANGLES 30-50 DEGREES

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NASA HQ EC80 2470(1)
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Figure 1. - Hours per year of expected outage on a satellite link due to rain*.

PROGRAM STRUCTURE

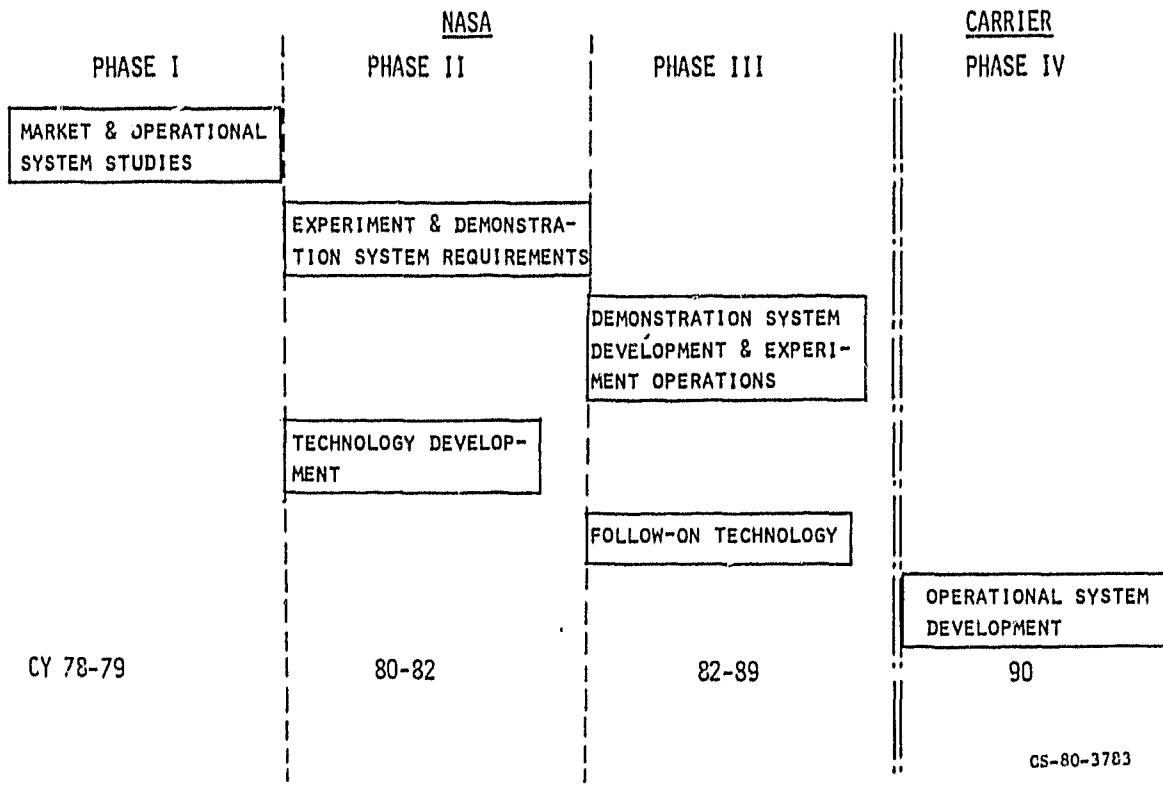
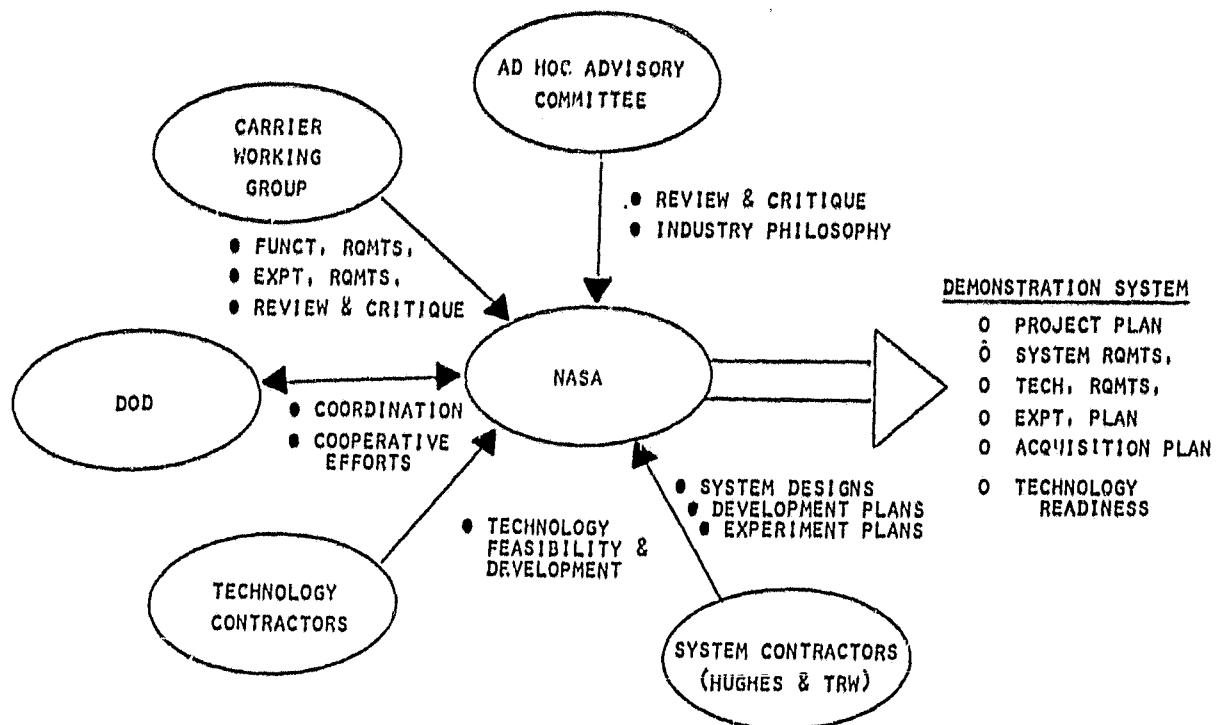


Figure 2. - Program structure.



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Figure 3. - 30/20 GHz demonstration system planning.

OBJECTIVE

- PROVIDE THROUGH FEASIBILITY DEMONSTRATIONS THE TECHNOLOGY REQUIRED TO ENABLE A COST-EFFECTIVE AND SPECTRUM-CONSERVATIVE IMPLEMENTATION OF THE K_A-BAND
- DECREASE DEVELOPMENT RISK FOR FLIGHT SYSTEMS

SCHEDULE GOALS

- BY END OF CY 82, COMPLETE THE NECESSARY TECHNOLOGY DEVELOPMENT REQUIRED TO SUPPORT DETAILED DESIGN AND FABRICATION OF HARDWARE FOR THE FLIGHT DEMONSTRATION SYSTEM

PHILOSOPHY

- PARALLEL CONTRACTS FOR ALL KEY SUBSYSTEMS

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Figure 4. - 30/20 GHz technology ready program.

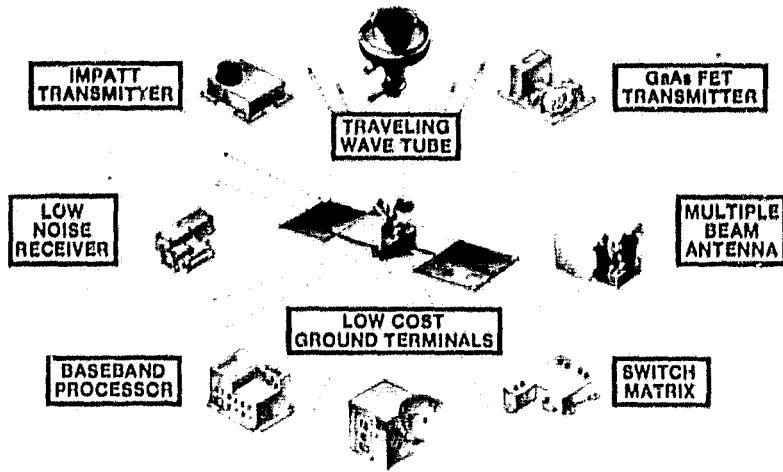
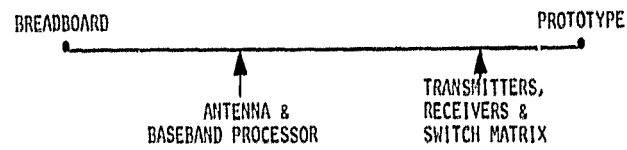


Figure 5. - 30/20 GHz communications project technology development elements.

- POC CONFIGURATION
COMPLETE SUBSYSTEM BUILT AND TESTED USING (IN MOST CASES)
FLIGHT TYPE MATERIALS

- POC MODEL VARIATIONS



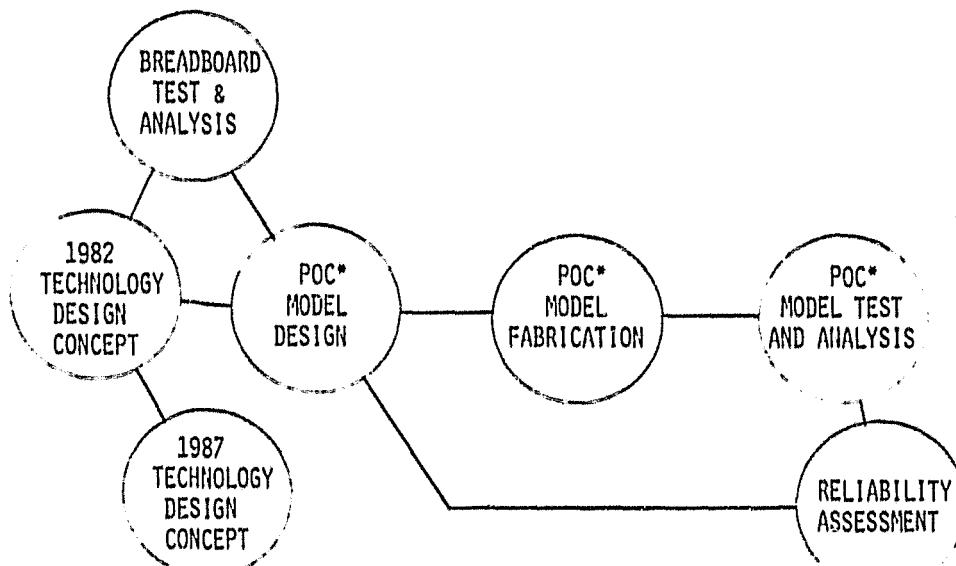
- POC TESTING
 - FUNCTIONAL
 - THERMAL VACUUM EXCEPT FOR ANTENNA

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Figure 6. - 30/20 GHz technology ready program.

<u>SUBSYSTEM/ELEMENT</u>	<u>COMPANY</u>	<u>CONTRACT VALUE (\$M)</u>
ANTENNA SYSTEM	FORD	2.7
	TRW	3.2
TRUNKING MATRIX SWITCH	FORD	.9
	G.E.	1.5
BASEBAND PROCESSOR	MOTOROLA	4.7
LOW NOISE RECEIVER	LNR	.6
	ITT	.8
GAAS FET TRANSMITTER	TRW	1.0
	TEXAS INSTRUMENTS	1.0
IMPATT TRANSMITTER	TRW	.9
	LNR	.4
TWT EXP. MODEL	HUGHES	.8
TWT XMTR W/PPS	TRW	.8
TRANSPONDER DESIGN STUDY	HUGHES	.2
K-BAND LATCHING SWITCHES	TRW	.3
TRANSPONDER SIMULATION	-	.6
LOW COST GROUND TERMINALS	-	3.2
SATELLITE - SWITCHED FDMA FOR CPS	-	<u>2.4</u>
CS-80-3799	TOTAL	26.3

Figure 7. - 30/20 GHz technology contract summary.

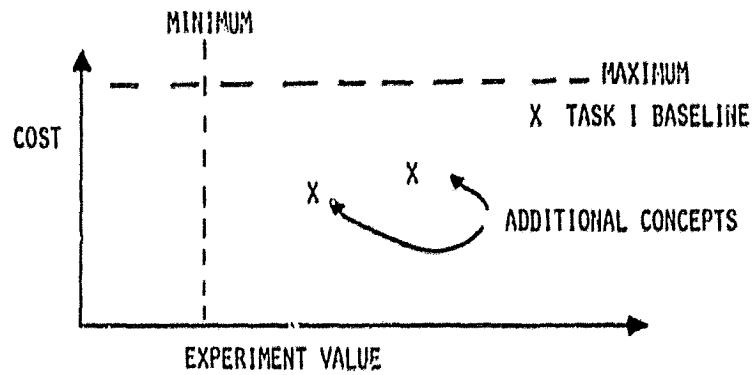


* PROOF-OF-CONCEPT

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Figure 8. - 30/20 GHz technology ready program - general contract structure.

- DEVELOP SYSTEM DESIGNS FOR VARIOUS REQMT'S



- PROVIDE SCHEDULES & COSTS FOR Ø III DEVELOPMENT
- PROVIDE DATA BASE FOR Ø III SEB

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Figure 9. - Phase II - Alternate design concept studies HAC & TRW.

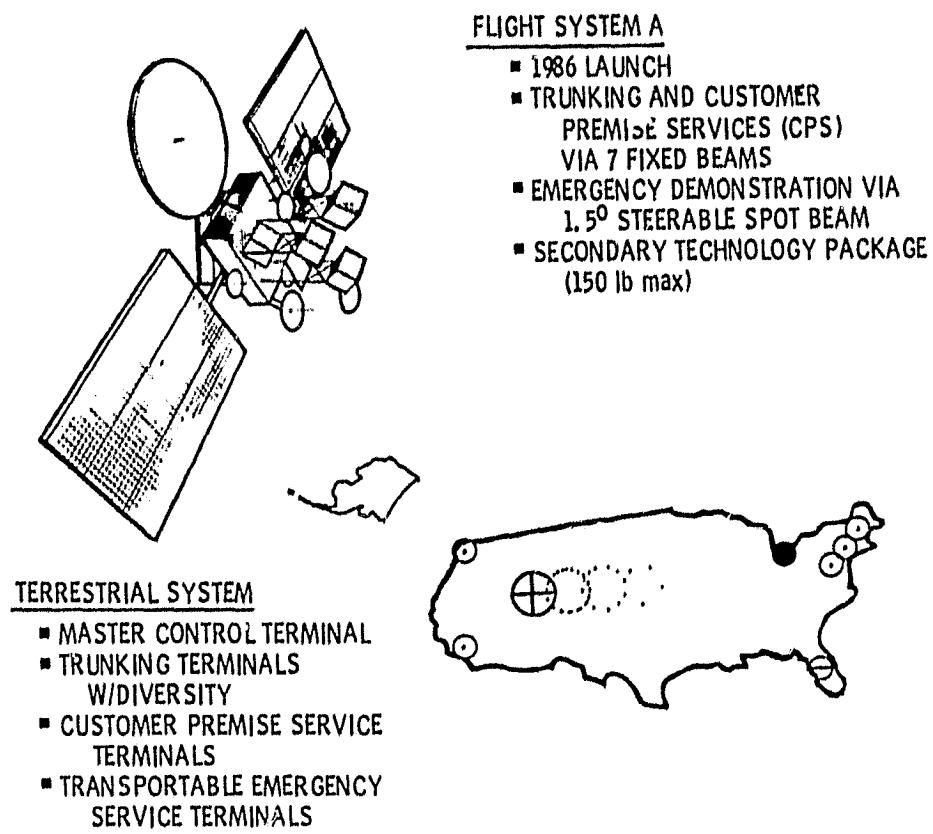


Figure 10. - 30/20 GHz communications system - Mission A.

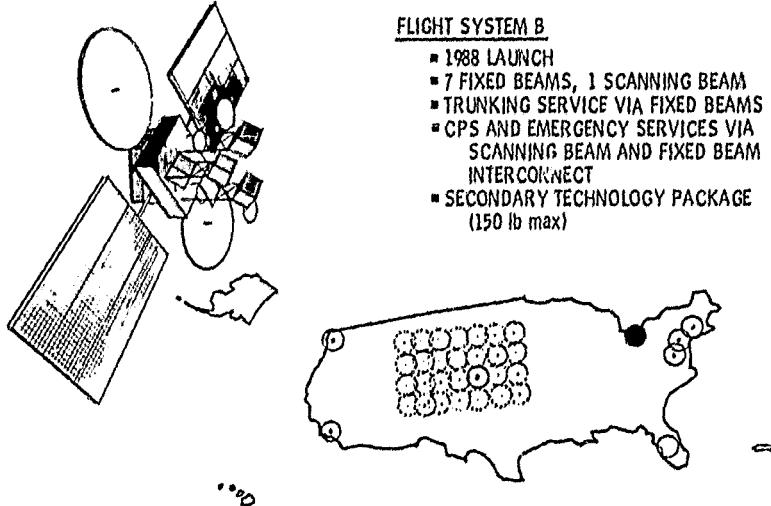


Figure 11, - 30/20 GHz communications system - Mission B.

- CLASS
 - SSUS - A
- WEIGHT
 - 2800/3000 LBS ON-ORBIT (BOL)
 - 600/800 LBS COMM. PAYLOAD
- BUS
 - COMMON BUS FOR MISSION A & B
 - UTILIZATION OF EXISTING BUS
- LIFETIME
 - TWO YEARS COMM. PAYLOAD
 - SEVEN YEAR SPACECRAFT
- CAPACITY
 - 43,000 VOICE CIRCUITS (2.8 GBPS)

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Figure 12, - Summary description - spacecraft,
30/20 GHz communications demonstration system.

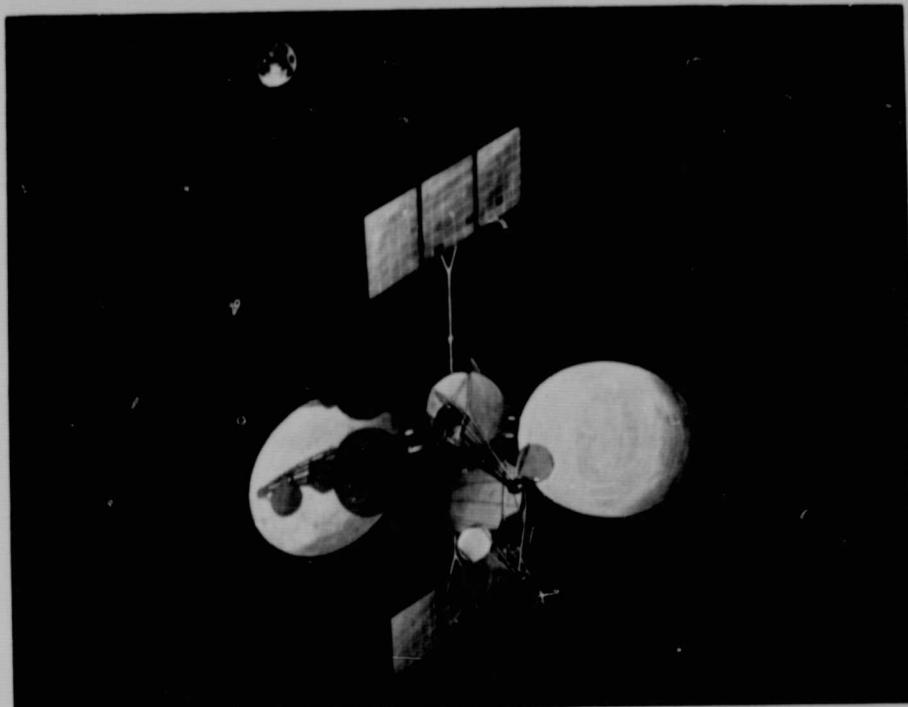


Figure 13.

- SUS A CLASS S/C
 - LIQUID APOGEE MOTOR WITH MINIMUM PERIGEE FIRING
- FLEETSATCOM STRUCTURE
- FLEETSATCOM/TDRSS SUBSYSTEMS/COMPONENTS USED TO MAXIMUM EXTENT POSSIBLE
- TT&C
 - UNIFIED S-BAND FOR ASCENT, BACKUP ON-ORBIT
 - 30/20 GHZ ON-ORBIT
- ATTITUDE CONTROL
 - RF SENSORS (CLEVELAND AND L. A.) FOR 3 AXIS CONTROL
- ELECTRICAL POWER
 - ULP SOLAR ARRAY TECHNOLOGY
 - NICKEL HYDROGEN BATTERIES
- REACTION CONTROL
 - NASA STANDARD 1 POUND HYDRAZINE THRUSTERS

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Figure 14. - Spacecraft design features.

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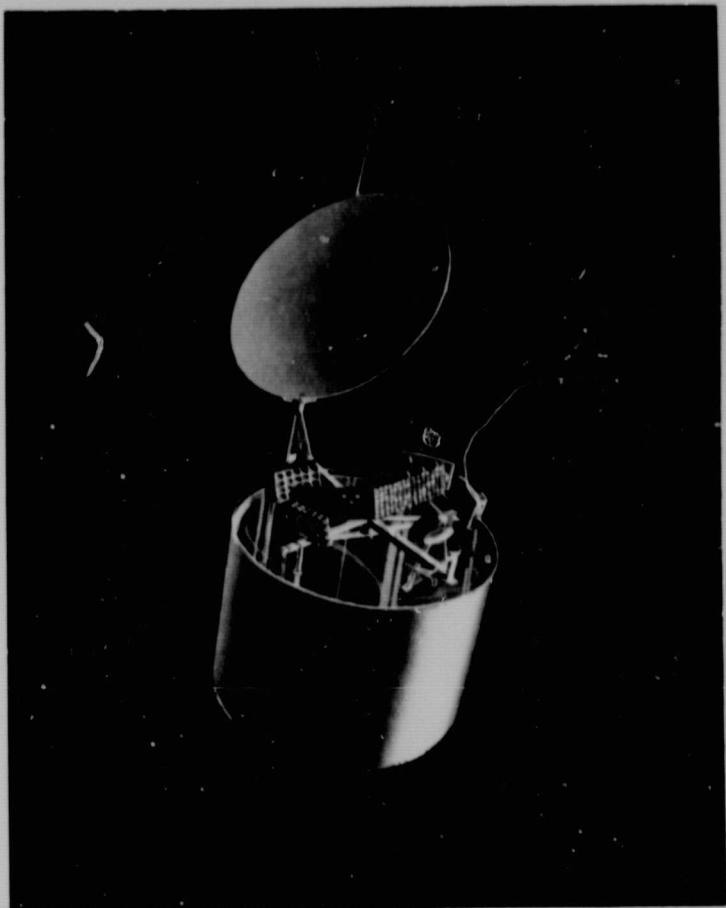


Figure 15.

- LEASAT SPACECRAFT BUS
- SPIN STABILIZED
- TT&C
 - UNIFIED S-BAND FOR ASCENT
 - 30/20 GHz ON-ORBIT
- ATTITUDE CONTROL
 - EARTH BASED BEACON (SBS SYSTEM)
- ELECTRICAL POWER
 - NICKEL-HYDROGEN BATTERIES
 - MODIFIED LEASAT SOLAR PANELS, K7 CELLS

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Figure 16. - Spacecraft design features.

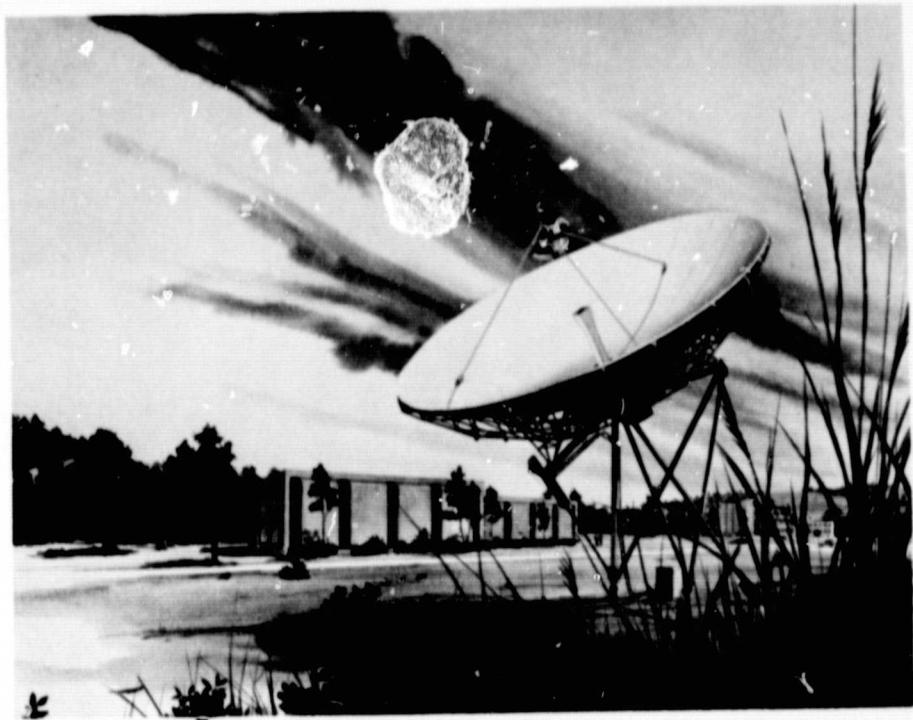


Figure 17.



Figure 18.



Figure 19.